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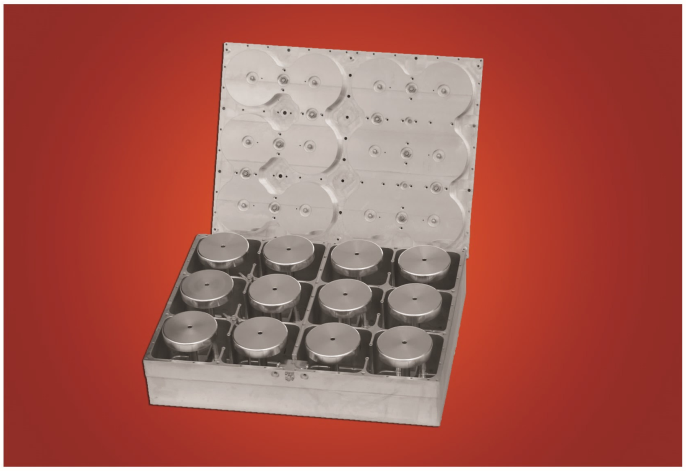

Compact, High Isolation, Low Loss VHF Diplexer

R&D Microwaves, LLC, a rapidly growing manufacturer of high quality passive microwave components for the cellular infrastructure market, recently added high performance cavity filter products to its suite of products. One of the first successes in the subject market niche was a VHF diplexer that utilizes cavity resonators to meet unusually difficult electrical performance goals in an electrically small package. R&D achieved this success by assembling an expert team to design, manufacture, assemble and test the subject diplexer.

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R&D MICROWAVES, LLC.

In This Issue

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Compact, High Isolation, Low Loss VHF Diplexer

by R&D Microwaves, LLC

R&D Microwaves, LLC, a rapidly growing manufacturer of high quality passive microwave components for the cellular infrastructure market, recently added high performance cavity filter products to its suite of products. One of the first successes in the subject market niche was a VHF diplexer that utilizes cavity resonators to meet unusually difficult electrical performance goals in an electrically small package. R&D achieved this success by assembling an expert team to design, manufacture, assemble and test the subject diplexer. The team approach allowed delivery of this high performance component within a very short time schedule.

R&D Microwaves, LLC led the team and provided the mechanical design work, assembly, tuning and testing. The electrical design work was provided by Alford Microwave Consultants, LLC. The machined component manufacture was provided by Ryan Company. Expert engineering talents within the design team utilized modern, powerful CAD and CAM tools like WIPL-D to achieve a "first build" success.

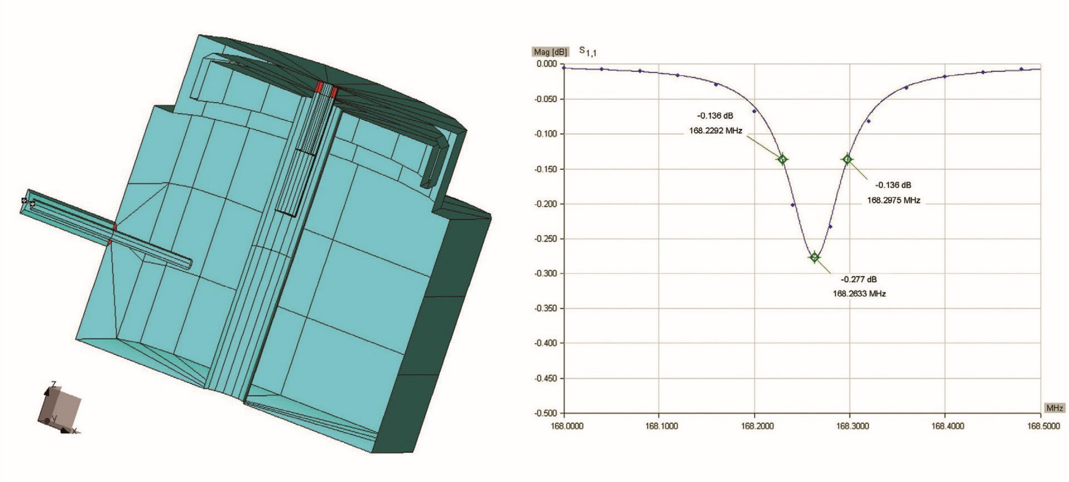

Figure 1: WIPL-D Resonator Model and "Sniffer Port" Return Loss Response

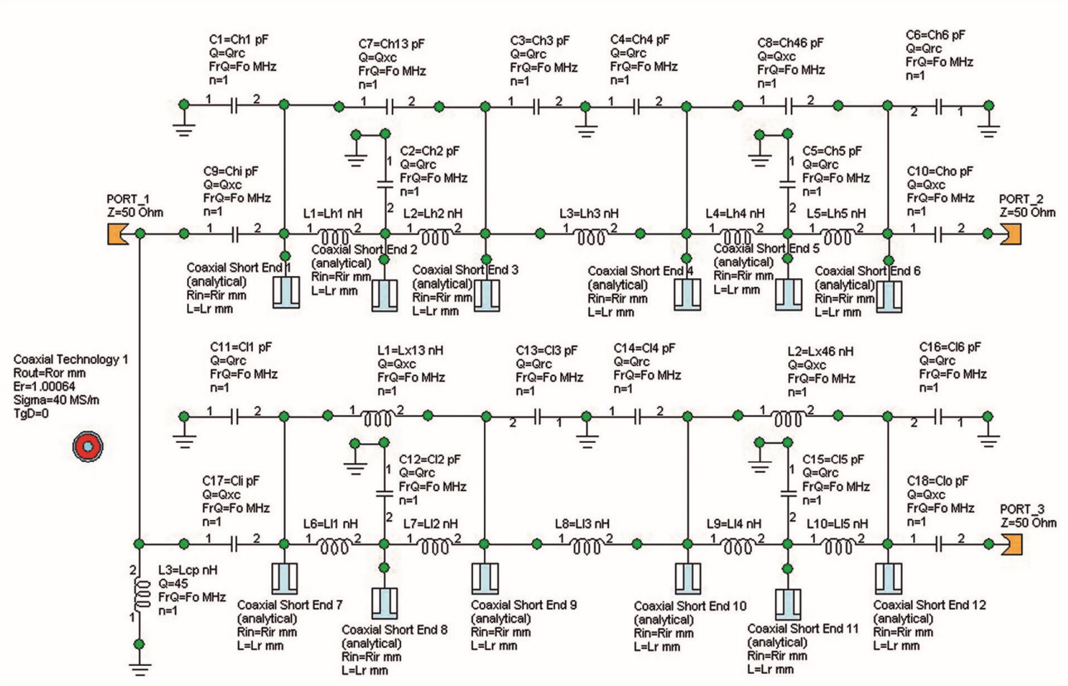

Figure 2: WIPL-D Microwave Pro Diplexer Equivalent Circuit Model

Electrical Design Background Information

Large structures like aircraft, ships, and satellite ground station antennas represent difficult Electro Magnetic (EM) simulation challenges. This is because traditional EM simulation methods based on volume discretization lead to near impossible demands on computation resources, especially as frequency increases. Method of Moments (MoM) based EM simulation strategies are known to generally require reduced computation resources because surface discretization is normally employed.[1] WIPL-D pioneered the use of higher order basis functions on larger structural elements with a MoM based solution engine to bring the computation resource demands of larger structures within the capability of widely available personal computers and workstations.

Small, complex structures like electronic circuits and cavity filters have traditionally been simulated with volume discretization methods because the accurate modeling of such structures requires structural elements that are much smaller than a wavelength and naturally consistent with very simple basis functions. However, very often the complexity and/or physical size of the device causes the same computation resource problems presented by large structures. Such higher complexity electronic devices can be simulated with MoM EM strategies; however, most commercial MoM tools are not fully 3D capable.

When the design requirements lie in the VHF frequency range, efficient designs often

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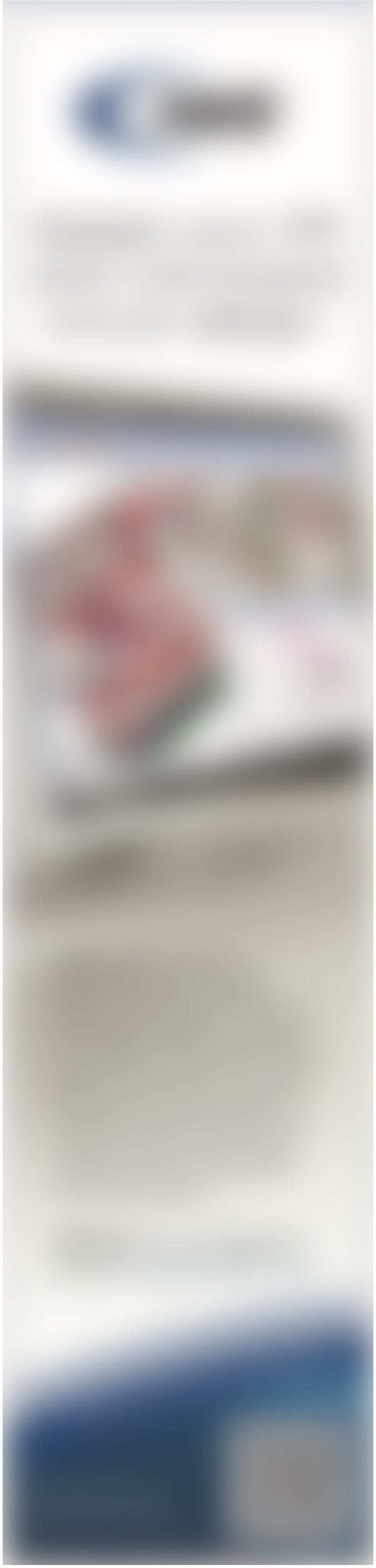

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require the use of both distributed and lumped elements. WIPL-D offers a suite of EM analysis tools that can be used to efficiently simulate complex electronic devices using mixed elements. The following sections of this article describe the design of a high performance VHF diplexer that uses mixed elements.

Electrical Performance Requirements

The subject VHF diplexer required that two 4.3 MHz pass bands centered at 164.3 and 171.7 MHz be isolated by greater than 85 dB while providing less than 2 dB insertion loss between the common port and the appropriate band port. These electrical performance parameters had to be achieved in a package volume of no more than 0.0024 cubic wavelengths (12" x 16" x 4.25").

Using mathematical models[2], it was determined that filters with six resonators and two cross couplings would provide the required band to band isolation, and the resonator unloaded Q must be approximately 2000 to provide the specified in-band insertion loss.

Resonator 3D EM Model

The high unloaded Q required of the resonators suggested a distributed element (cavity) resonator; however, the operating frequency suggested a lumped inductor-capacitor resonator. A helical resonator may have been a good choice, but a practical design guide[3] indicated that the required Q was very near the high side limit for a resonator made of copper or silver operating at the desired center frequency. Use of expensive copper or silver in the resonators for the subject devicewould have impacted costs in a negative way, especially when manufactured at the large quantities projected. Therefore, it was decided to determine if the resonators could be made of unplated aluminum to keep costs at a minimum. WIPL-D Pro CAD, an accurate, economically priced 3D EM tool, was used to evaluate the practicality of an all aluminum cavity resonator.

Figure 1 shows the WIPL-D resonator model developed for the subject diplexer filters, and the predicted return loss at the "sniffer port" for aluminum conductivity set for the internal resonator surfaces.

Well known techniques[2] were used to determine the half-power points of the response as shown in Figure 1 (-0.136 dB). The "sniffer port" represents a very light loading on the resonator, so the loaded Q and unloaded Q are very near the same. Therefore, based on the frequencies marked in Figure 1, the unloaded Q is approximately 2400. This represents a 20% margin over the target number of 2000, leading to the conclusion that an un-plated aluminum resonator of this size and shape would provide the required electrical performance. This model was also used to determine the tuning sensitivity of the various physical parameters that roughly correspond to envisioned equivalent circuit elements.

Equivalent Circuit Model

Knowledge of the physical size and shape of the resonators (see previous section) allowed creation of a more accurate equivalent circuit model for the subject diplexer. The most obvious elements of the resonator were a shorted length of coaxial line with heavy capacitive loading on its open circuit end. Microwave Pro, the circuit based tool in the WIPL-D suite, was used to develop the equivalent circuit model.

Figure 2 shows the WIPL-D Microwave Pro equivalent circuit of the subject diplexer. The coaxial short end elements were dimensioned to represent the corresponding lower part of the resonator 3D EM model. The initial values of the resonating capacitors were set to the values of simple flat plate capacitors with the plate areas, gaps and dielectrics of top regions of the 3D EM model. The initial values of the cross-coupling capacitors and inductors were determined using simple J-inverter models[4] that provide the coupling coefficients determined in the mathematical model.

The circuit of Figure 2 was optimized to obtain the response shown in Figure 3, which was compliant with the required electrical performance.

Multi-resonator Coupling Models

The values and connection points for the inter-resonator coupling elements shown in the equivalent circuit model were either not realizable or not practical. The input and output resonator coupling capacitors had practical values, and, due to the heavy loading on those resonators, direct connection to the resonators was also practical. Using WIPL-D Pro CAD, multiple coupled resonator models were developed to evaluate and select practi-

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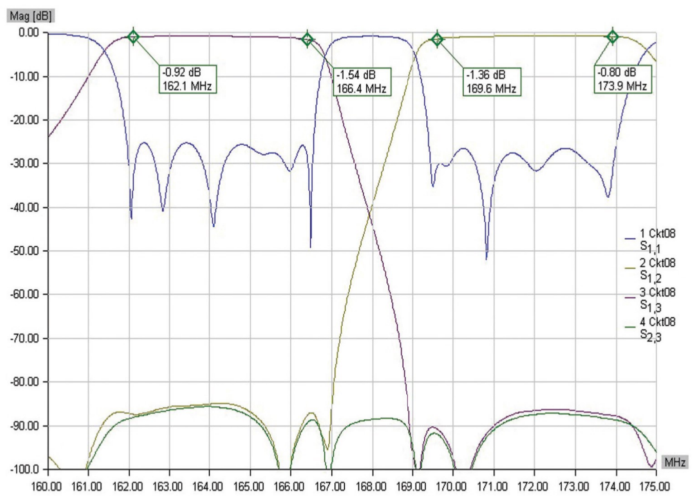

Figure 3: Electrical Performance Prediction from Equivalent Circuit Model of Figure 2

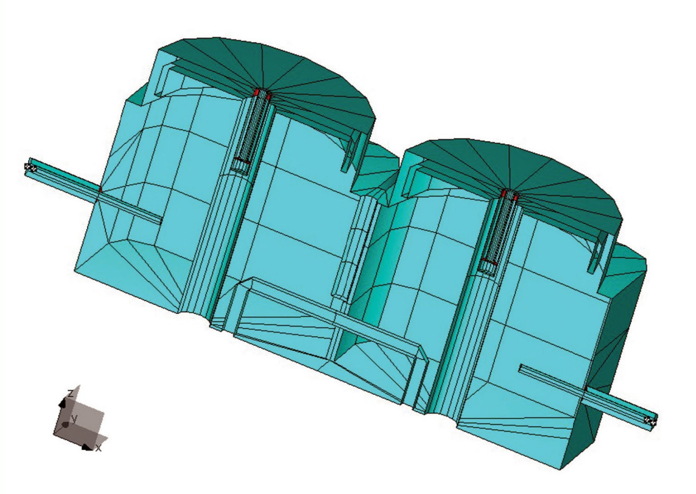

Figure 4: Main Path Inductive Coupling Model

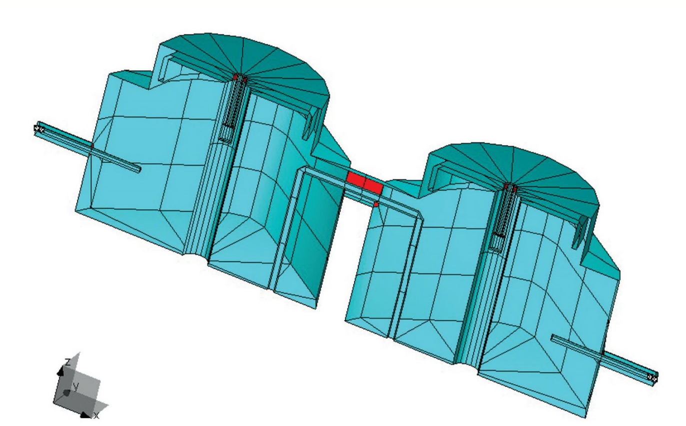

Figure 5: Inductive Cross Coupling Model

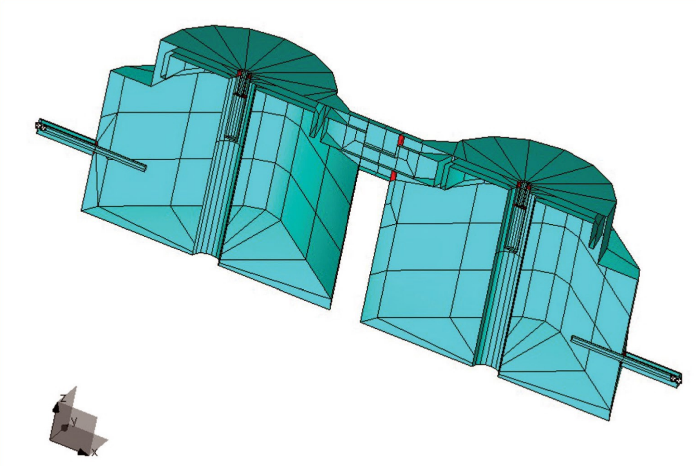

Figure 6: Capacitive Cross Coupling Model

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cal structures of the inter-resonator couplings.

Figures 4, 5 and 6 show the two resonator models used for the selected main path inductive couplings, inductive cross couplings and capacitive cross couplings, respectively. The models in Figures 5 and 6 use WIPL-D Pro CAD's lumped RLC loading capability to simulate lumped air variable tuning capacitors at the midpoint of the cross coupling elements. A three resonator coupling model was used to determine dimensions of elements with accuracy consistent with first build

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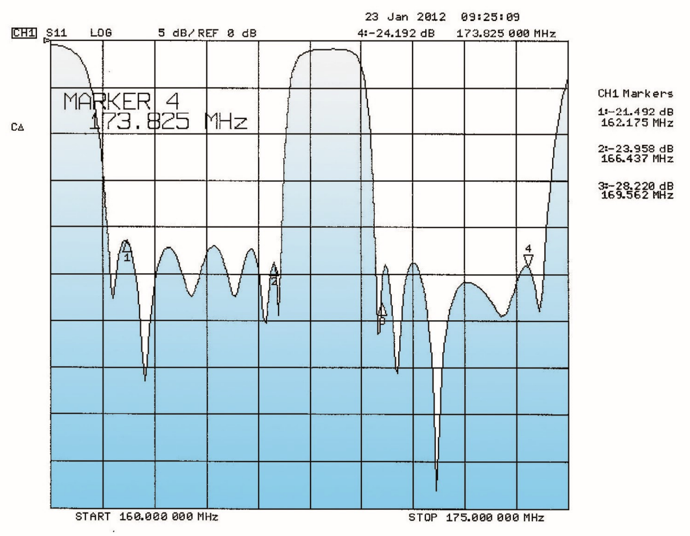

Figure 7A: Common Port RL

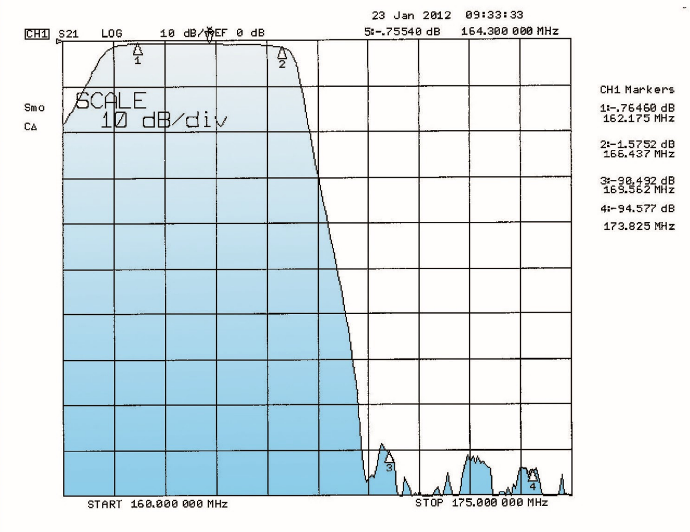

Figure 7B: Low Band IL

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success (minimal tweaking to determine final production part dimensions).

All WIPL-D Pro CAD models used a maximum patch size settings of 0.0045 λ or smaller for the required accuracy; this setting for the three resonator model resulted in a solver problem with 18,466 unknowns that needed only 88 minutes to solve 11 frequency points on a HP xw8600 workstation with two 2.5 GHz Xeon CPUs, 16 GB RAM and a 3 GB VRAM Nvidia GTX580 GPU video card. WIPL-D Pro CAD offers GPU processing capability when the hardware has CUDA enabled video card(s).

Summary and Conclusions with Actual Performance Data

This paper described the design of a high performance VHF Diplexer utilizing the unique combination of capabilities in the WIPL-D suite of 3D EM analysis and optimization tools. Actual performance data from one of the first units manufactured is shown in Figure 7A, 7B, 7C & 7D, confirming the accuracy, speed and validity of using MoM based 3D EM tools to design electrically small, but electrically complex passive microwave devices.

References

[1] Kolundzija, Branko, "Electromagnetic Modeling of Composite Metallic and Dielectric Structures," IEEE Transactions on Microwave Theory and Techniques, Volume: 47, Issue: 7, July 1999.

[2] Cameron, Kudsia and Mansour, "Microwave Filters for Communication Systems," John Wiley & Sons, Inc., 2007.

[3] ITT, "Reference Data For Radio Engineers", Howard W Sams & Co. Inc., Fifth Edition, March 1969.

[4] Matthaei, Young & Jones, "Microwave Filters, Impedance-Matching Networks, and Coupling Structures," McGraw-Hill Book Company, 1964.

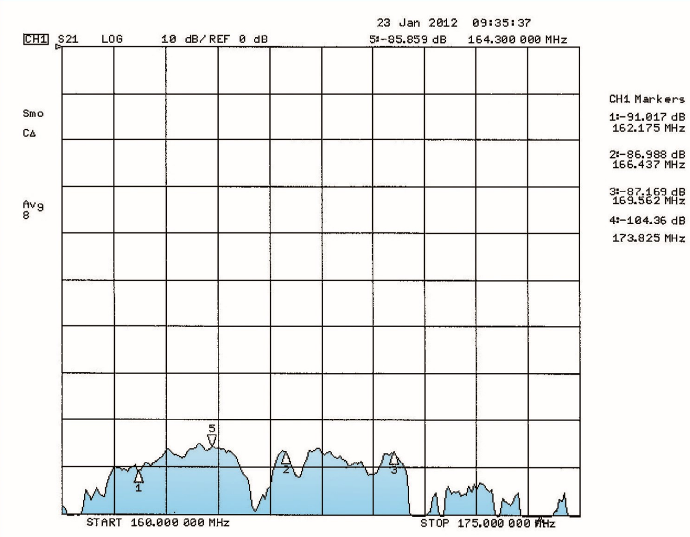

Figure 7C: Band to Band Isolation

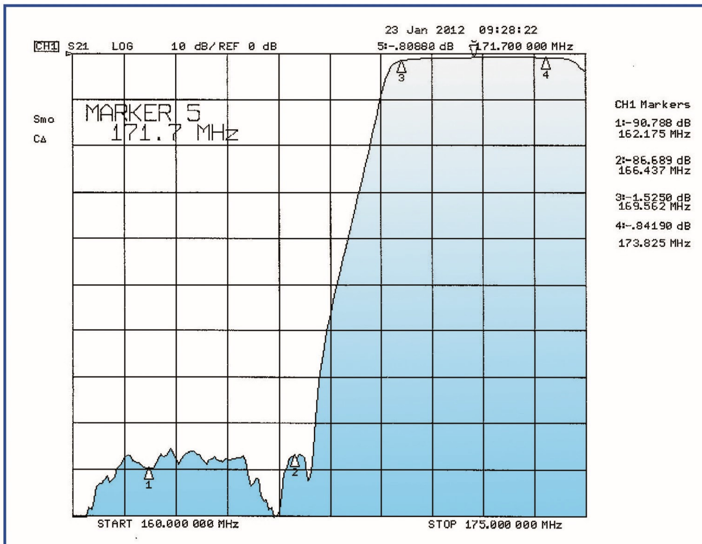

Figure 7D: High Band IL